IN PUBLICA COMMODA, CREATING BARRIER-FREE EDUCATIONAL STATISTICS VIDEOS FOR HIGHER EDUCATION: INSIGHTS AND EVIDENCE FROM DEAF PEOPLE USING GERMAN SIGN LANGUAGE (DGS)

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ABSTRACT

To address diversity-sensitive higher education, we provide the first results exhibiting the importance of the use of German Sign Language (Deutsche Gebärdensprache, DGS) in lecture videos of elementary statistics courses. We examined whether deaf individuals preferred lecture videos in DGS over those with captions. Results from quantitative and qualitative analyses on the basis of survey data and interview material in DGS indicate a clear preference for teaching materials in DGS. While the limited sample size (n = 10) did not allow for detailed modeling of the underlying reasoning, this study puts forward some indicative results and directions for future research, like assessing objective learning outcomes by employing pre- and post-tests and employing eye-tracking for more in-depth analysis of learning behaviors.

A summary of this paper in International Sign is (will be) available on the website of the Sign Language Lab of the University of Göttingen: https://www.uni-goettingen.de/de/publikationen/679740.html

Keywords: *Statistics education research; German Sign Language; inclusive education; interview analysis*

1. INTRODUCTION

Data literacy is an important skill not only in the context of one's professional life but also in one's everyday life. Many instances of decision-making rely on statistical and data-driven approaches (Bilgin et al., 2020; Engel, 2017; Frischemeier, 2020). A notable recent example of the importance of data literacy skills was the COVID-19 pandemic, which required individuals of all backgrounds to make decisions on both an individual level and a societal level (Bilgin et al., 2020). Furthermore, given the numerous other areas in professional and private life where data literacy is helpful or even necessary, we deem it self-evident that virtually everyone benefits from fundamental statistical education.

The ongoing digitalization at universities also presents new opportunities for accessibility which allow us to convey fundamental statistical insights to a wider audience than ever before. Teaching videos are an essential part of this undertaking. In order to ensure the widest possible accessibility for all, it is essential to collaborate together with persons with different disabilities and accessibility needs on an equal footing, adopting a participatory community-based approach (Finkbeiner et al., 2023b). It is also important to emphasize that inclusion can provide new impetus for fundamental change. The abandonment of familiar thought structures and the adoption of new perspectives can generate innovative ideas (Grote, 2018). To further contribute to the scholarship on this topic, we present in this article initial insights and empirical evidence from an inclusive blended learning teaching project for an interdisciplinary introductory statistics module for undergraduate students.

1.1. DEAF STUDENTS AND GERMAN SIGN LANGUAGE

"One of the most striking aspects of language is that it can be processed and learned as easily by eye-and-hand as by ear-and-mouth – in other words, language can be constructed out of manual signs or out of spoken words" (Goldin-Meadow & Brentari, 2017). Just as different spoken languages are used in each country, there are different sign languages as well. Deaf people naturally communicate with sign languages using the hands, arms, face, head, and upper part of the body in the visual-spatial modality. Members of the German Deaf Community[1] use German Sign Language (Deutsche Gebärdensprache, DGS) and deaf[2] people in Italy, for instance, use Italian Sign Language (Lingua dei segni italiana, LIS).

While the provision of captions and/or a transcript of auditive information is of course often helpful for deaf audiences, this type of information is provided in a language that is, in fact, non-native to many deaf persons as German and DGS are wholly different languages, each with their own grammar.

There are many linguistic differences at all levels of grammar when comparing spoken and written German to that of DGS, such as the formation of linguistic units, sentence structures, and sentence types (Eichmann et al., 2012; Finkbeiner et al., 2023a; Kleyboldt, & Hillenmeyer, 2016a, b). Sign languages are performed in the visual-spatial modality and follow a visual logic that is important for deaf people's understanding. As in spoken languages, technical signs or jargon also exist in sign languages. The online-based lexicon Sign2MINT, which contains over 5,000 STEM technical terms in DGS, is very helpful for educational videos in the fields of mathematics, statistics, and other subjects (https://www.sign2mint.de/; Barth et al., 2022). The DeafDidactics team at the Aachen Competence Center for Sign Language and Gesture (SignGes) offer key impetus for teaching in sign language. The term *DeafDidactics* refers to a teaching method in a sign language that creates coherence between a visually oriented organization of knowledge for deaf and hard of hearing pupils and visual teaching methods and materials (Grote et al., 2022). Werner et al. (2019) suggest that DGS in the visual-spatial modality opens up other approaches for mathematics lessons, which could stimulate different learning potentials in inclusive learning groups. There is an urgent need to incorporate sign language-sensitive approaches to mathematical knowledge into teaching practices. The STEMSiL (STEM in sign languages) consortium, which is co-funded by the European Union, is also engaged in efforts to enhance STEM education for deaf children (STEMSiL, n.d.). Their objectives extend beyond supporting educators to additionally involve the development of methodologies and tools designed to facilitate the inclusion of deaf pupils in STEM-related subjects (https://stemsil.eu/).

In 2021 the World Health Organization (WHO) published the "World Report on Hearing." Over 200 people contributed to this report, which addresses the impact hearing loss has on various aspects of life, including education and employment. In 2021 nearly 20% of the global population was affected

[1] The term "Deaf Community" encompasses a community of deaf and hard of hearing people whose core is sign language, sign language culture, and way of life of deaf people. They define themselves on sociocultural terms rather than on a raw medical description of the hearing deficits. There are different Deaf Communities such as a Berlin Deaf Community, a German Deaf Community, and an International Deaf Community (Finkbeiner et al., 2023a).

[2] We use the term "deaf" more broadly and also include hard of hearing people who feel they belong to the Deaf Community and communicate primarily in a sign language.

by some degree of hearing loss. From these, approximately 430 million people have at last moderate hearing loss, equating to over 5% of the global population. The use of sign languages and captions represents a means of providing deaf people with barrier-free education (WHO, 2021). It is estimated that around 80,000 deaf people live in Germany, with DGS being used by at least 200,000 to 250,000 people (Rubarth, 2023; Wheatley et al., 2012). However, it is challenging to provide precise figures for Germany and the rest of the world, as there is no standardized survey and definition of the degree of hearing loss at which someone is considered deaf in a medical sense. Furthermore, not all countries collect data on this. Nevertheless, it can be estimated that approximately 0.1% of the global population is deaf (Finkbeiner et al., 2023a). This equates to approximately 70 million individuals worldwide who are deaf or profoundly deaf. For these individuals, sign languages represent a crucial means of participation in the world (World Federation of the Deaf (WFD), 2016).

The United Nations Convention on the Rights of Persons with Disability of 2006 stipulates in article 24 that persons with disabilities have a right to "receive the support required, within the general education system, to facilitate their effective education […]" (United Nations [UN], 2006, Art. 24, 2d) and that "support measures are provided in environments that maximize academic and social development, consistent with the goal of full inclusion" (UN, 2006, Art. 24, 2e). The German government formally approved the treaty in 2009 (UN Treaty collection, 2024). However, several authors in Germany note that higher education is still marred by manifold barriers and that by-and-large inclusion is pursued by a haphazard, ex post, patchwork approach rather than realizing the potentials of planned inclusion into higher education (Podszus & Schulze, 2023; Poskowsky et al., 2018). This is also confirmed by many self-reports from people who encounter such barriers. Especially for the provision of digital (open) educational resources, public sector universities would formally be obliged to pursue their barrier-free provision and the EU Directive 2016/2102 on the accessibility of the websites and mobile applications of public sector bodies and the derived national law of the Act on Equal Opportunities of Persons with Disabilities (Behindertengleichstellungsgesetz, BGG/AEPD). These laws refer to the Web Content Accessibility Guidelines (WCAG) of which the current Version 2.2 stems from 2023 (World Wide Web Consortium, 2023) While the WCAG offer several levels of conformance, the highest-level AAA does explicitly entail the use of a sign language for pre-recorded teaching videos.

1.2. BLENDED LEARNING WITH DEAF STUDENTS

The recent years have seen a movement toward the provision of digital elements for teaching statistics at the authors' university and elsewhere. For example, in a study comprising 10 pupils, Schäfer et al. (2022) investigated the utilization of videos in sign language in conjunction with mathematics lesson materials in written language and their impact on subject matter comprehension.

Providing these digital elements has allowed teaching at the authors' university to be conducted increasingly in a blended learning format, which we understand as learning formats "that combine face-to-face instruction with computer mediated instruction" (Graham, 2007). While we would like to stress that the provision of digital teaching materials should ideally be complemented by a face-to-face setting, we will focus on digitally provided lecture video materials and in particular their potential to provide more inclusive conditions for deaf students. Thus, we leave the equally important question of how to provide an inclusive face-to-face setting for deaf students aside for the moment.

1.3. ASSESSING THE IMPORTANCE OF MATERIALS USING SIGN LANGUAGE FOR DEAF STUDENTS

We aim for the reduction of barriers faced by students in general and those who are deaf or hard of hearing in particular. In light of this, we have considered and continue to consider the possibility of providing additional or modified digital materials that would enable students to individually work without encountering the unfortunately widespread barriers to comprehension. As previously stated, one such barrier to comprehension for deaf students is usage of teaching materials involving spoken or written German language alone without the provision of DGS. This constitutes a language barrier for students who were raised using a sign language. Consequently, we hypothesize that the contents of the teaching videos are more challenging to comprehend for deaf students if they are provided in a written

format, such as captions or transcripts, due to the said language barrier. In contrast, we expect that teaching videos in DGS should facilitate comprehension as well as be more engaging for deaf students.

However, given the financial constraints in our educational system, one critical question is whether providing DGS is necessary or whether captions are sufficient. In order to provide some initial empirical evidence for this inquiry, this paper addresses the following research question:

"Do deaf persons have a preference for German Sign Language (DGS) over spoken language captions in German statistics videos, finding them more convenient for comprehension and interest?"

To answer this question, we conducted a preliminary study with newly developed lecture materials from a data literacy course aimed to impart fundamental data competencies. In particular, we investigate the perceived differences in comprehension between captions for content in spoken German and a free translation in DGS, as well as the preferred video format.

The following section presents the employed video segments, as well as the data collected from questionnaires and interviews with ten deaf participants. Subsequently, we present analyses of the aforementioned data. The results are then summarized in the conclusion.

2. DATA

For our preliminary study, we conducted a mixed methods analysis comprising both quantitative and qualitative data. We invited ten deaf participants to the Sign Language Lab at the University of Göttingen. The participants took part in three different studies on the day they were there. One of these studies is the subject of the present paper, which consisted of educational video segments on data literacy in combination with a metadata questionnaire, a statement questionnaire, and a qualitative interview. To allow for extrapolations beyond tertiary education, we chose both students and non-students as participants. Furthermore, a range of ages and backgrounds were considered. The study was conducted entirely in DGS by a deaf native signer (co-author of this paper). No hearing persons were present during the study.

2.1. DESIGN OF THE VIDEO SEGMENTS

As part of our preliminary study, we selected short segments from existing lecture videos of the data literacy project "DaLeLe4ALL – Daten Lesen Lernen für Alle" (Learning to Read Data for Everyone), which aims to impart fundamental data competencies to a broad audience. The content of these videos is based on the award-winning data literacy course "DaLeLe – Daten Lesen Lernen." (Learning to Read Data).[3] The course is designed for undergraduate students from various disciplines, including economics and social science, as well as degree courses for teacher training (Lasser et al., 2021).

The video segments were presented to the participants in two different versions: one version was in spoken German with captions and the other in DGS. Screenshots of each version are provided in Figures 1 and 2. Figure 1 portrays the original lecturer speaking with captions below him and Figure 2 portrays a deaf sign language interpreter translating the contents of the video into DGS. In terms of video design, the video with captions can be divided into three areas where the participants can potentially direct their attention: the slides, the lecturer, and the captions (see Figure 1). In contrast, the DGS version encompasses only two areas: the slides and the deaf interpreter (see Figure 2).

[3] The award was presented by the "Stifterverband für die Deutsche Wissenschaft."

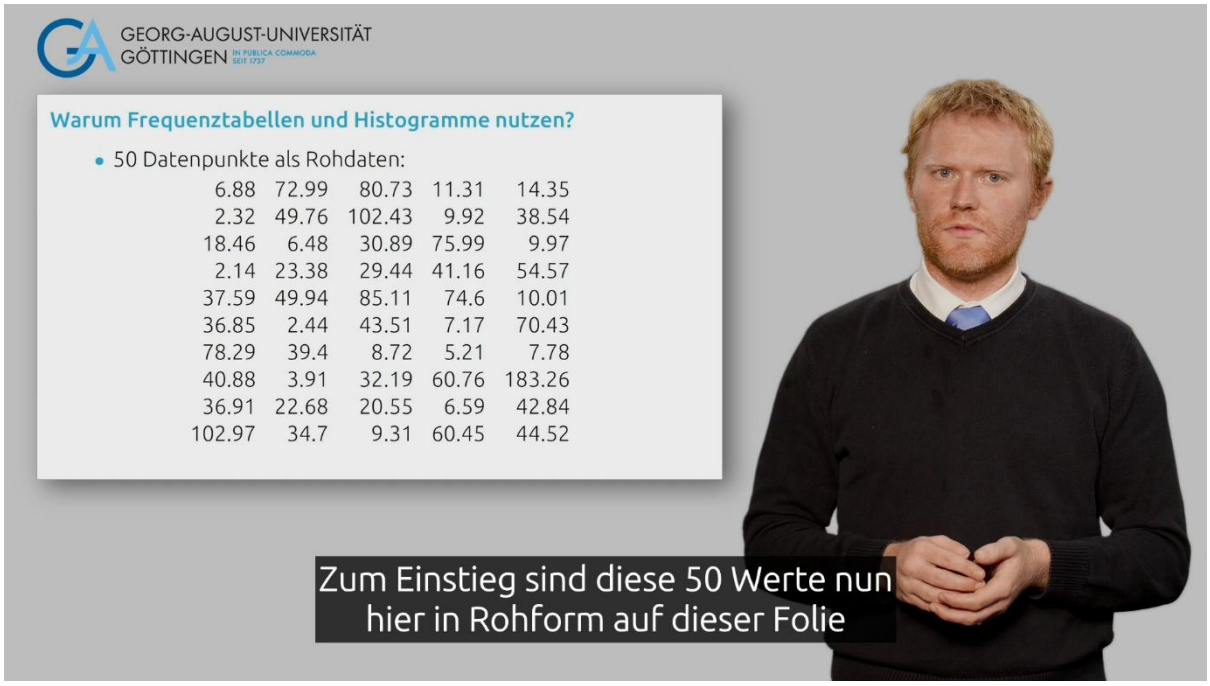

Figure 1. Screenshot of video segment "Histogram" in the captioned version (hearing lecturer)

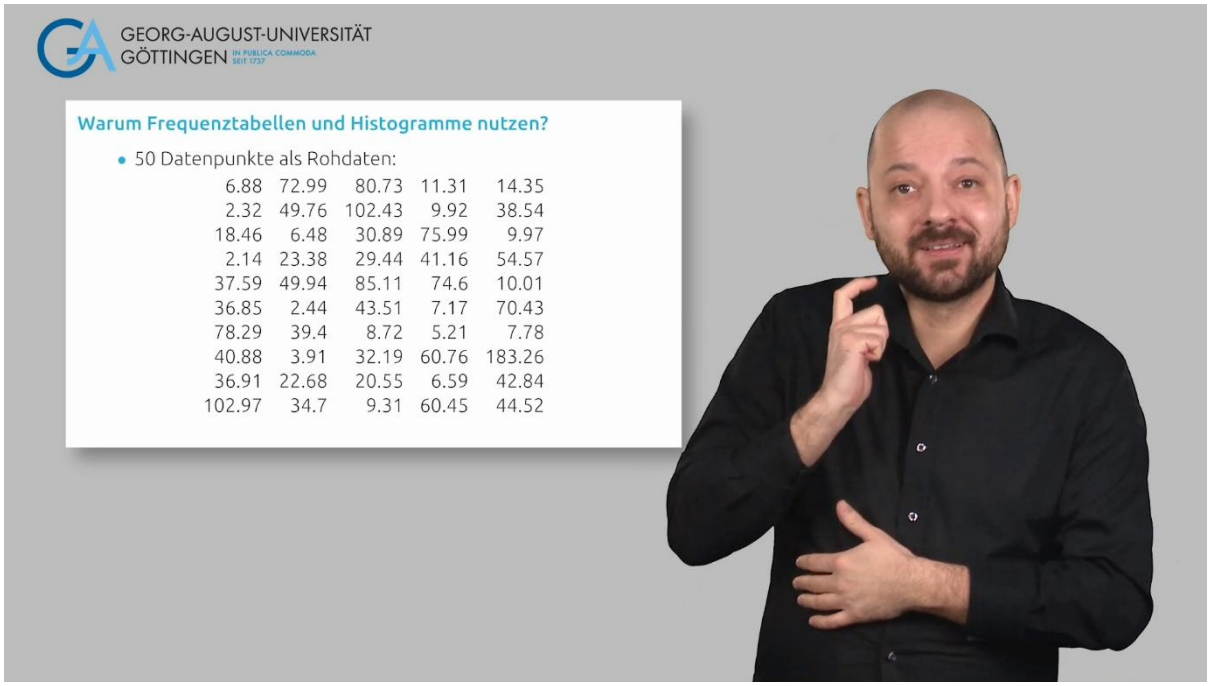

Figure 2. Screenshot of video segment "Histogram" in DGS version (deaf interpreter)

In both versions, the lecturer/interpreter can be seen on the right side while the slides are on the other side. The slides are in the background so that the lecturer/interpreter can use as much space to gesture/sign as necessary and still be seen in front of the slides, for which an example is provided in Figure 3. In this manner, the interpreter is sufficiently large that all aspects of DGS, including hand, arm, head, and body movements as well as facial expressions within the upper and lower face (Pendzich, 2020), are visible at all times.

The captions, only included in the version with the hearing lecturer, are located in the bottom middle of the video rather than on the slides in order to avoid concealing information. Furthermore, the captions do not exceed two rows for readability and are displayed in white on a black background to improve

visibility (see Figure 1). For a good contrast between the signing hands and the background of the video as well as an aesthetically pleasing and easily perceivable overall design, we decided to use a gray background (see Figure 3).[4] As shown in Figure 2 and Figure 3, the clothing of the signing person is monochromatic and dark.

For this study, four short video segments were selected from four different lecture videos. The video segments with captioning are between 45 seconds and two minutes long. The video segments in DGS are between one and four minutes long. The time difference between both versions is a result of having chosen unrestricted translations into DGS. The general content of the segments was identical in both versions. We deliberately allowed translations to be conducted more freely without the pressure of having to conform to spoken language structures. In this way, the deaf interpreter could choose the optimal form of presenting in DGS and could follow a visual logic in the signed text structure.

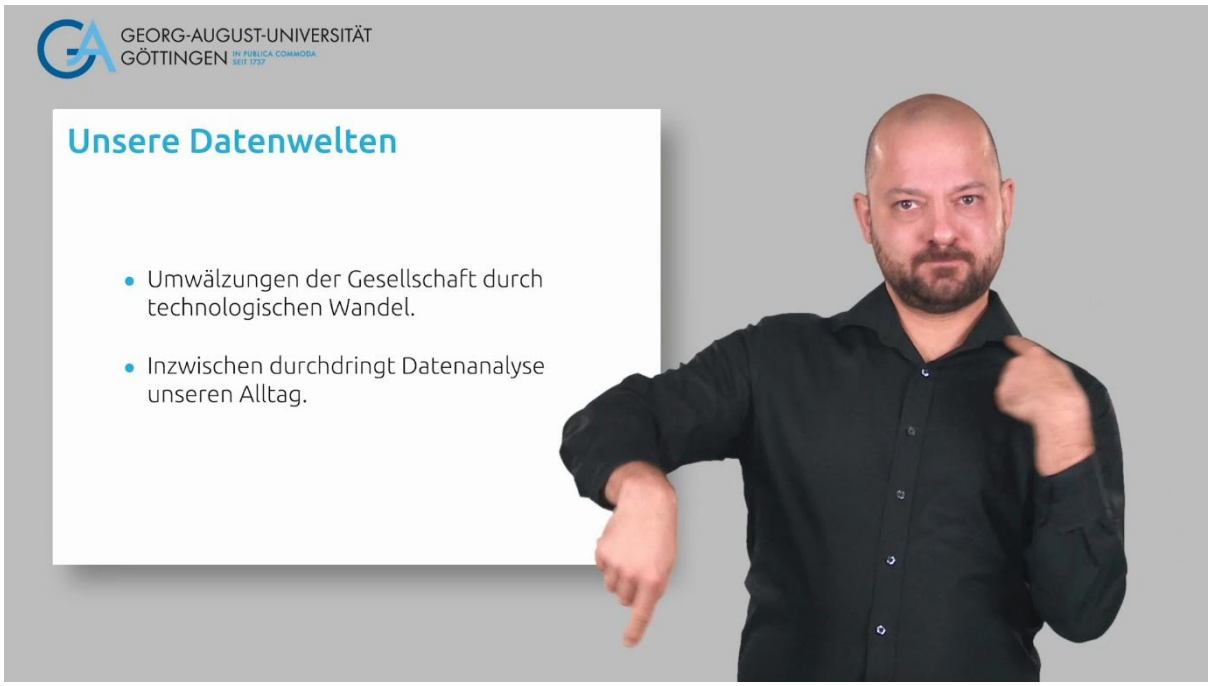

Figure 3. Screenshot of a video with interpreter in front of the slides

The videos were shown to our deaf participants in increasing difficulty in terms of abstraction and notation. All videos aimed to impart fundamental data competencies. Table 1 gives an overview of the number of views per video version in the sample. The first shown video segment concentrates on the increasing volume of data today and is referred to as "Data World" in Table 1 and throughout the paper. The second video explains the use of a flow chart for algorithms and is referred to as "Algorithm." The third video is a segment of a lecture about location measures in statistics concentrating on the calculation of the arithmetic mean and is referred to as "Arithmetic Mean." The last shown video segment explains frequency tables in preparation for their use in histograms and is referred to as "Histogram." Figure 1 and Figure 2 show a screenshot from this "Histogram" video segment in the captioned version and in the DGS version respectively, while Figure 3 contains a screenshot from the "Data World" video segment in DGS.

Each participant was shown both versions of the video segments (with captions and with DGS). Due to an unforeseen technical issue with an originally planned eye-tracking component, the randomization of the order structure was unsuccessful for four of the ten participants. To account for this problem, we randomized the selected video segments ex post, downsizing the available sample size

[4] Based on our experiences and the needs of visually impaired people we now use a slightly darker grey in our lecture videos (see also the hints of the Bundesarbeitsgemeinschaft der Taubblinden e.V.: https://bundesarbeitsgemeinschaft-taubblinden.de/wp-content/uploads/Gebaerdenvideos-und-UT_endversion.pdf).

from 80 observations to 40 observations; each participant was randomly assigned one of the two versions per video segment thereby halving the observations. Consequently, only four video segments watched by each participant are included in the analyses, rather than all eight segments watched. For the following quantitative analyses, we thus used a sample for which each participant was randomly assigned one version for each of the four videos with equal chance, thus entailing between zero and four video segments with captions or in DGS per participant. Table 1 provides an overview of the views per video version.

Table 1. Overview of views per video version in the sample

	Video segment			
	Data World	Algorithm	Arithmetic Mean	Histogram
Views with captions	6	6	3	7
Views with DGS	4	4	7	3

2.2. THE QUESTIONNAIRES AND INTERVIEWS

Metadata questionnaire. After a welcome and some small talk, information about the study was provided to the participants. The participants were asked to fill out a standardized metadata questionnaire, which is used by the Sign Language Lab at the University of Göttingen by default, and a statement questionnaire after each video segment. Additionally, the participants were provided with a privacy policy.

The metadata questionnaire contained questions regarding their age, education, as well as their communicative and social history. Both questionnaires were translated into DGS, ensuring that while the participants were asked to tick the appropriate option, they were not required to only read the questions. During the viewing of the video segments and the completion of the statement questionnaires, participants were seated in a room with the deaf native co-author. This co-author was present in case of questions, but otherwise kept a low profile and stayed in the background.

The participants' ages ranged from 18 to 65, with an arithmetic mean of 42 years. Concerning education, we constructed the sample in such a way to roughly represent the general education structure in Germany (Statistisches Bundesamt, 2020). Accordingly, 30 % of the participants (three participants) fell into the International Standard Classification of Education (ISCED) categories 0, 1 and 2 and another 30 % fell into the ISCED categories 3 to 4. The remaining 40 % (four participants) were in ISCED categories 5 to 8.

Interviews. Prior to the viewing of the video segments and completion of the statement questionnaire, qualitative interviews were conducted. A second round of interviews were conducted after viewing the videos and completing the statement questionnaire. In the first round of qualitative interviews, participants were queried about their experiences with mathematics and their time at school. The second round of qualitative interviews concentrated on key points relating to the videos they watched. The participants were asked to describe their impression of the videos: what they liked and what they did not like, as well as how comprehensible the videos were, both with captions and in DGS. They were also asked to reflect whether they would have liked these kinds of videos during their school years and if they can recall situations in which these kinds of videos would have been helpful (or would be helpful). Furthermore, the participants were asked to describe their impressions of the structure and design of the videos. Finally, all participants were asked what they would prefer: only captions, only DGS, both at the same time, and/or an additional transcript of the respective video.

Both parts of the qualitative interview were recorded on video and conducted by the deaf native co-author in DGS with each participant individually in a conversational format designed to foster a relaxed atmosphere conducive to open communication. The participants did not read the interview questions. Instead, the interviewer used the open questions (see Appendix) as focal points in the conversations. It should be noted that the questions were not necessarily asked in exactly the prepared form and/or order during the interview if the participant had already referred to the content of the questions during the course of the conversation-like interview. Depending on the course of the interview, additional follow-

up questions were also asked in some cases. Thus, there was no narrow question-answer structure and the participants were encouraged to give additional information and stories.

Statement questionnaire. After every video segment, the participants were asked to fill out a questionnaire with five statements on a five-point Likert-scale ranging from "I completely disagree" to "I completely agree" with "I neither disagree nor agree" in the middle, which were also visualized by Harvey balls in the questionnaire. This procedure yielded 10 responses for each of the video segments. Following the randomization process, only 10 responses per video topic were utilized, with the distribution between the caption and the DGS version as seen in Table 1. A total of 40 responses were obtained, with 22 derived from captioned video segments and the remaining 18 from video segments in DGS.

In the following analyses, we focused on the five statements from the statement questionnaire that employed a Likert scale for responses:

Statement 1: "I liked the video."
Statement 2: "The video has caught my interest."
Statement 3: "I was able to follow the content of the video."
Statement 4: "I can reproduce the contents of the video."
Statement 5: "The speed of knowledge transfer was pleasant."

The first statement, "I liked the video," represents a general assessment of the participants, which is based on subjective factors. The subsequent four statements inquire about potential explanations that could influence a participant's agreement or disagreement with statement one. The second statement, "The video has caught my interest," may be indicative of a participant's willingness and motivation to watch the video attentively, given the assumption that interest encourages the motivation to follow lecture content. The third and fourth statements assess the ability of deaf participants to learn content displayed in the videos. Following Thomas and Bain (1984), the third statement is designed to subjectively assess the participants' intake of the video, while the fourth statement is intended to provide a subjective indication of their ability to reproduce the content, akin to a hypothetical performance control. The last and final statement specifically addresses the aspect of information overflow. On the one hand, this concerns knowledge transfer in the form of captions in comparison to DGS. On the other hand, this statement focuses on the parallel perception of different sources of information via the eyes: either the presentation slides and captions (and possible the lecturer) or the presentation slides and the signed content by the deaf interpreter. We hypothesize that the use of DGS within the video segments contributes positively to the agreement of the participants to all of the five statements as compared to the captions. Thus, DGS should enhance the interest of the participants in, as well as their ability to follow and reproduce the content compared to the caption versions of the video segments.

3. ANALYSIS

First, we provide descriptive statistics for each of the five statements with respect to the video version shown. Second, we give an overview of the results from the qualitative interviews.

3.1. DESCRIPTIVE ANALYSIS

Figure 4 to 8 are visualizations of the response patterns of the ten participants to the five statements in form of clustered distribution bar charts. In every figure the first four clusters refer to the video versions with captions and the last four clusters refer to the video versions in DGS. Every figure therefore shows the response pattern for every video segment. Each cluster consists of up to five bars relating to the 5-point Likert-scale ranging from "completely disagree" to "completely agree" with "neither disagree nor agree" in the middle. Additionally, Table 2 gives an overview of the median answers by participants for each statement per video segment.

Figure 4 depicts the clustered bar charts for Statement 1, "I liked the video."

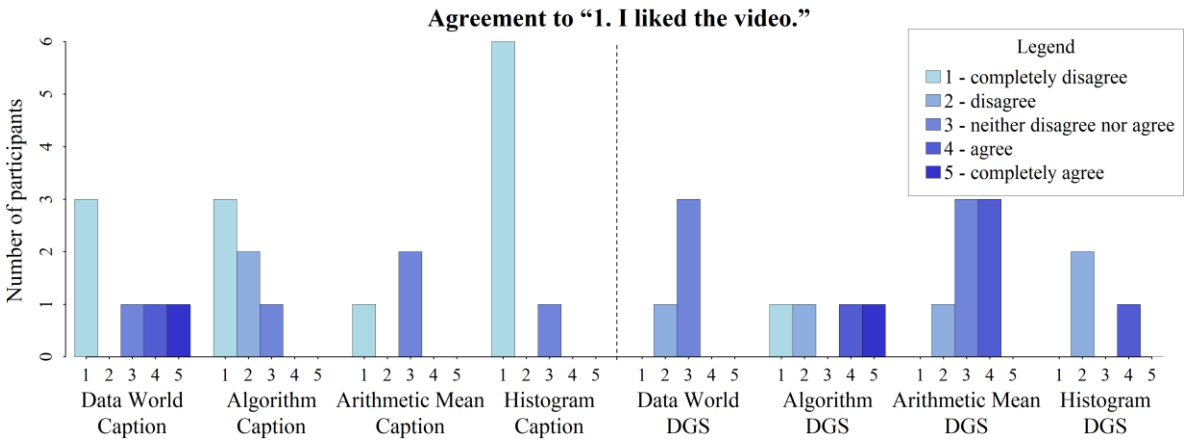

Figure 4. Clustered bar charts of agreement to Statement 1 by video segment

The participants seem to like the caption version of this video less than the DGS version. This is visible, for example, in the "Histogram" segment. With regard to the DGS version, one participant selected "agree" to the statement "I liked the video," while none selected "completely disagree." In contrast, for the caption version, none selected "agree," while six selected "completely disagree." The median agreement in Table 2 also demonstrates this for the different video segments, as the median for the caption versions is less than that of the DGS versions, with the exception of the "Arithmetic Mean" segment, where both versions resulted in a median agreement of "I neither disagree nor agree."

Table 2 further shows that the median of the answers of the participants is between "completely disagree" and "neither disagree nor agree" for all the videos regarding the first statement "I liked the video." Although, for three of the four videos the median agreement is "neither disagree nor agree" for the DGS version, while the median agreement for the version with captions is between "completely disagree" and "disagree" for three of the videos. Thus, considering these median agreements and the distribution of the responses depicted in the bar charts, the DGS versions seem to be perceived as somewhat more likeable than the versions with captions.

Table 2. Overview of median agreement to statements by video segment in both versions

	Video segment							
	Data World		Algorithm		Arithmetic Mean		Histogram	
	Captions	DGS	Captions	DGS	Captions	DGS	Captions	DGS
Statement 1	2.0	3.0	1.5	3.0	3.0	3.0	1.0	2.0
Statement 2	3.5	2.5	2.5	3.0	2.0	4.0	1.0	2.0
Statement 3	3.5	4.0	2.5	3.0	1.0	4.0	2.0	3.0
Statement 4	3.0	3.5	2.0	3.0	2.0	4.0	2.0	3.0
Statement 5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Note: The agreement to the statements is measured on a five-point Likert-scale with 1 being "I completely disagree," 2 being "I disagree," 3 being "I neither disagree nor agree," 4 being "I agree" and 5 being "I completely agree."

Figure 5 depicts the clustered bar charts of the answers to the second statement, which show that the level of agreement to Statement 2 tends to be higher for the DGS version compared to the version with captions for three of these four video segments. The medians in Table 2 reinforce this tendency. This indicates that the videos in DGS caught the participants interests more than the videos with captions.

The only exception is the "Data World" video segment; the median agreement is 3.5, which means that it is in between "neither disagree nor agree" and "agree" for the version with captions and 2.5, indicating a position between "disagree" and "neither disagree nor agree" for the DGS version. What may explain this result is that the "Data World" video segment is the easiest video with the least

complicated topic, such that it is well feasible that the participants understood the content sufficiently with the captions to have caught their interest.

The other three bar chart clusters in Figure 5 for the video segments with captions show a general trend that the rating of the agreement gets worse with increasing difficulty, with some videos being overwhelming for some participants. For the captioned version, the median for the "Arithmetic Mean" video segment is "disagree" and for the "Histogram" video segment it is "completely disagree." The difference in the median values presented in Table 2 also indicates that the median agreement is higher for the DGS versions than for the versions with captions of the video segments "Algorithm", "Arithmetic Mean" and "Histogram". Conversely, the median for the captioned version decreases with increasing complexity in the video topic from the "Data World" video to the "Histogram" video.

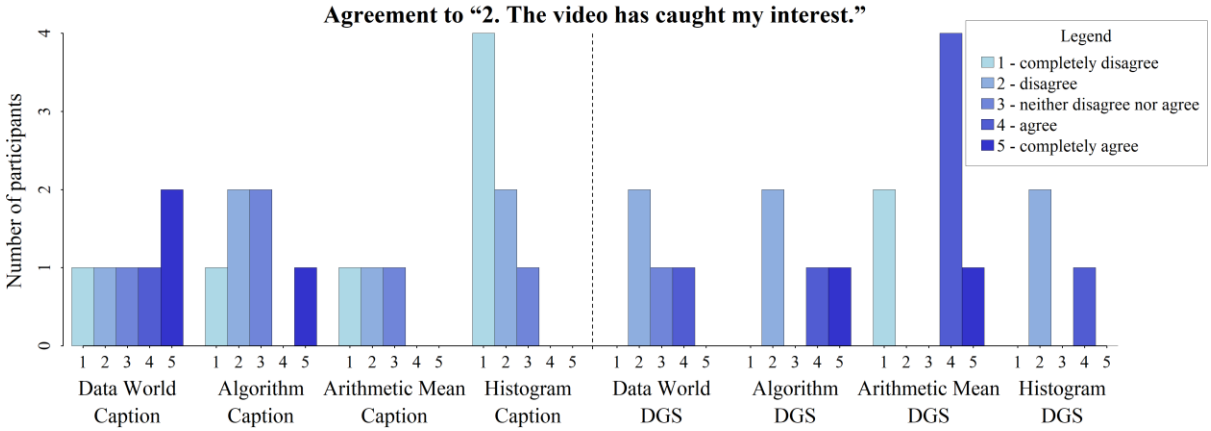

Figure 5. Clustered bar charts of agreement to Statement 2 by video segment

The increasing difficulty of the videos is also discernible in Figure 6, which depicts the clustered bar charts of the agreement of the participants to the third statement "I was able to follow the content of the video." Because of the increasing complexity of the video segments, we would expect the agreement to the statement to be lesser for the last two videos ("Arithmetic Mean" and "Histogram") compared to the first two videos ("Data World" and "Algorithm"). Furthermore, we again would expect the DGS version to be rated higher than the version with captions of a video segment. Both expectations are met and also evident in the medians in Table 2. Participants were more likely to follow the content of the videos when watching the DGS version than when watching the captioned version. The strongest difference is found in the "Arithmetic Mean" video segment. Here, the median of the participants' responses for the version with captions falls in the category "completely disagree," which means that the participants were not able to follow the content of the video when only captions were visible. At the same time, the median for the DGS version is "agree" and the participants could follow the lecture contents.

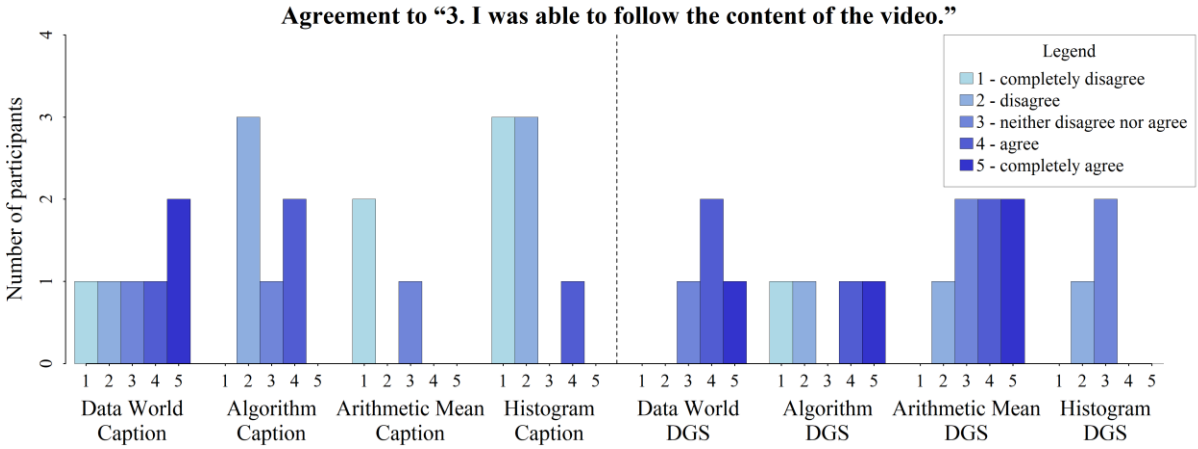

Figure 6. Clustered bar charts of agreement to Statement 3 per video segment

The responses to the fourth statement "I can reproduce the contents of the video" are visualized in the clustered bar charts in Figure 7. As previously observed, the level of agreement with the statement is higher with the DGS version than with the version with captions of the video segments. The responses to Statement 4 regarding the "Arithmetic Mean" video segment show that the perceived ability to reproduce the contents of the video was better with the DGS version compared to the version with captions. Further evidence for this assertion can be found in Table 2, which displays a greater median agreement for the DGS version than for the caption version across all four video segments.

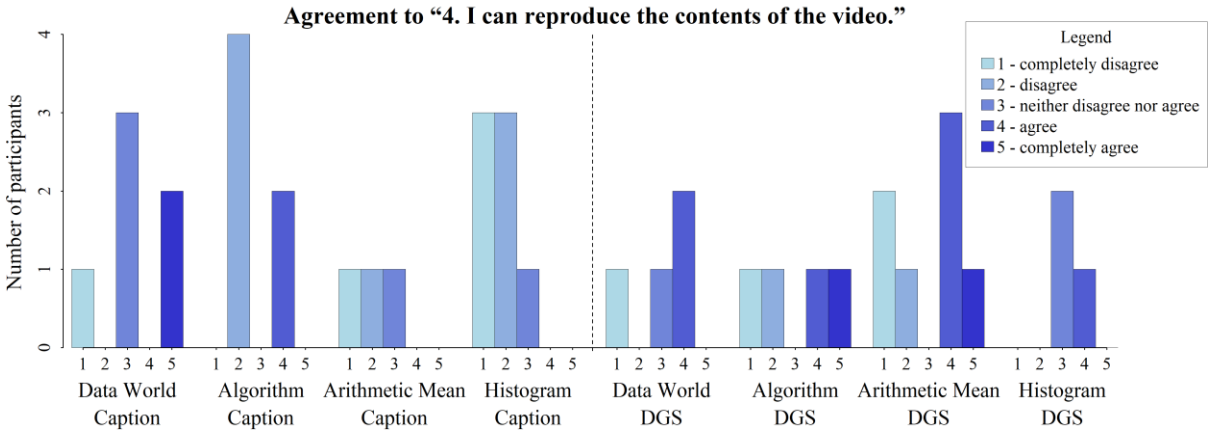

Figure 7. Clustered bar charts of agreement to Statement 4 by video segment

The clustered bar charts in Figure 8 show the level of agreement of the participants with the fifth statement "The speed of the knowledge transfer was pleasant." The median agreement in Table 2 for all videos except the version with captions for the "Data World" video segment falls in the "neither disagree nor agree" category. The median response for the "Data World" video segment with captions falls between the categories "neither disagree nor agree" and "agree." However, the clustered bar charts in Figure 8 suggest that the participants choose a higher category in agreement for the DGS version than for the version with captions.

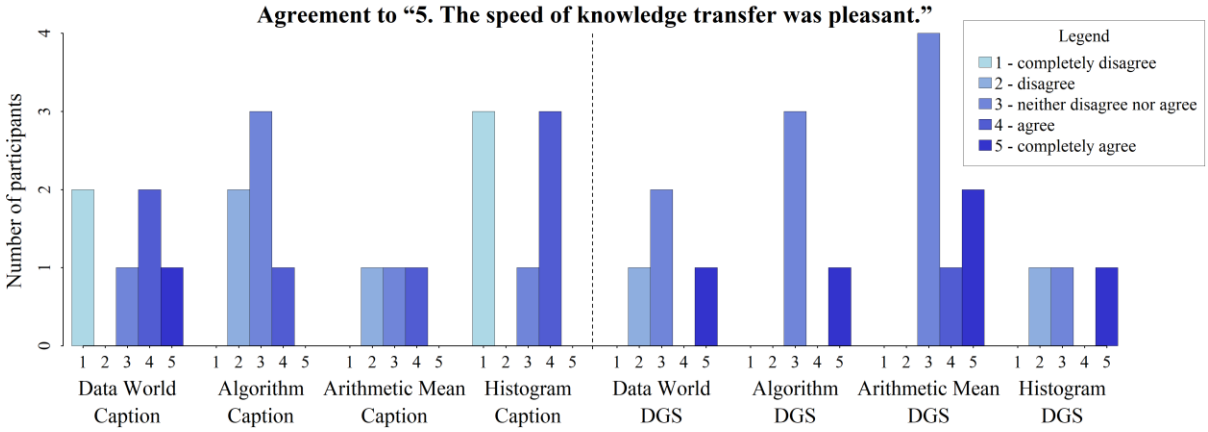

Figure 8. Clustered bar charts of agreement to Statement 5 by video segment

In summary, at the descriptive level, the reported agreement responses to Statements 2, 3, and 4 (Figures 5, 6, and 7) indicate that participants' interest in and ability to follow and reproduce the content is enhanced by viewing videos in DGS rather than videos with captions. Furthermore, the data indicates that the participants exhibited a preference for the video versions in DGS. However, they did not necessarily concur with Statement 1, which could be attributed to the complexity of the content, its focus on data literacy skills, and the fact that it is not an entertainment video.

These results are in line with the results of the study by Schäfer et al. (2022), which showed that sign language videos help deaf pupils aged 13 to 15 to deal with text problems in mathematics lessons and that the use of such videos proves to be very motivating.

3.2. INTERVIEW ANALYSIS

In order to validate and complement the findings from the survey data, we conducted qualitative interviews with the deaf participants before and following the watching of the videos and the completion of the statement questionnaire in the following manner.

To structure the interview, we jointly formulated open questions in advance. These questions were designed to elicit opinions from the participants on the aforementioned focal points in section 2.2. All interviews were filmed, resulting in a total of 125 minutes of DGS material. The analysis of the interviews was conducted following an inductive approach (Thomas, 2006). Analyzing the filmed material, the interviewing co-author carefully selected core statements from the interviews in relation to the themes of the quantitative analysis; themes otherwise deemed insightful were translated into German written language. Subsequently, the selected statements were organized by a second co-author in accordance with the identified focal points and discussed by the full team of co-authors, before being utilized for the analysis portrayed in the following.

A first insight from the interviews, was the embedding of the previously given responses in the diverse educative histories of the participants, with several participants reporting the challenges of content conveyance in school without any DGS translation. This resulted in it being necessary for them to engage in additional work outside of the school day in order to maintain their academic performance. Several participants indicated that there was no comparable provision of lecture videos in DGS during their school years. Furthermore, a participant mentioned the prohibition of sign language during their school years which stands in stark contrast to teaching materials being made available in DGS now.

These findings may in part explain the significant effect for Statement 1 as many participants may have expressed their affinity for the videos in DGS while considering their own challenging education history lacking materials in DGS being a considerable influence.

Turning the interview towards discussing the participants' impression of the video segments, yielded both points of approval and suggestions for improvement.

Translation into DGS. Many participants commended the use of DGS in the video segments. In particular, several participants expressed that they liked that the DGS translation was not a rigid translation of the spoken content, while some participants noted that the translation was still too direct

and that they would prefer an even freer translation, given that the structure of DGS differs substantially from that of spoken (or written) German. Consequently, they perceived the unrestricted translation to be more accessible than a direct translation. In line with our approach, numerous participants emphasized that DGS and captions are two distinct languages and that captions are not a substitute for the DGS version but rather complementary. One participant stated the importance of acknowledging that captions are not a replacement for accessible information. One participant indicated that they found it challenging to comprehend the videos with captions, so they would have had to watch these videos repeatedly. In contrast, with the DGS videos, they were able to grasp the content immediately. Another participant stated that they found captions and DGS useful, as they had a good command of the written language. Nonetheless, they found the DGS version more pleasant and lost interest in captions quickly, not least because the captions could not convey emotions whereas the signed versions could. These elaborations highlight the heterogeneity underlying the assessments with respect to statements 2 to 5.

Usage of captions. The interviews also pointed to further conflicting perspectives on the contrast between the DGS version and the caption version. Some participants indicated that they believe the DGS version is better overall, but that they require the captions for some segments like those including technical terms. One participant even stated that they prefer the DGS version, despite the difficulties with the technical terms. Another participant expressed that they would find watching both more beneficial—the DGS version first to gain an understanding for the content and followed by the captioned version to gain an understanding of the technical terms. A different participant proposed the use of a transcript (which we already provide for all our educational videos, but was not part of this study) in conjunction with captions to help in the comprehension of technical terms. One participant expressed in relation to the "Algorithm" video segment that even though they understood the words of the captions, they did not grasp the meaning behind the explanations. Another participant asserted that they perceived captions to be more suitable for technical terms, whereas sign language is more appropriate for applications and examples.

In consideration of a possible video version where DGS and captions are employed simultaneously, one participant reflected that they like to watch the news program in that manner. Another participant stated that they are not adversely affected by a simultaneous display of an interpreter and captions, and that they are able to determine where they wish to direct their attention. In contrast, another participant stated that they do not enjoy the simultaneous display of both, and that they would prefer to view the videos one after the other.

These qualitative findings thus highlight the diversity of opinions and perspectives when comparing the two tested versions as well as a hypothetical third version using both captions and a DGS translation in the same video. Notably, multiple participants expressed a preference for the availability of different options to selectively choose one of the three stated versions in a given context. Nevertheless, all participants expressed a preference for DGS and the importance of DGS material in their interviews.

Overall video design. Last but not least, the interviews provided important insights into the perception of the provided videos which are relevant to those pursuing best practices in video design and format. While the background color was generally regarded as satisfactory, one participant proposed that the color could be made slightly darker to enhance visibility. Also, some participants remarked that they perceived the slides as being too crowded and the font as being too small, while others found them to be adequately clear. Furthermore, some slides we perceived to contain an excessive amount of information, leading to comprehension difficulties within the allotted time. Another point raised was that the speed of the video was in some instances too fast for the complexity of the topic presented.

In addition, participants were queried about their opinions regarding the format of the video versions, which feature the slides on one side and the interpreter/lecturer on the other. Some participants indicated that they had no objections to the format of both versions. Furthermore, multiple participants indicated that pauses in speech are crucial for comprehending the captions and for examining the slides. Analogously for the DGS version, one participant observed that the interpreter incorporated pauses in signing, which was beneficial, while another participant indicated that they would have preferred more pauses to facilitate viewing the slides. In accordance with the aforementioned observations, one participant proposed that a version be created in which the slides and interpreter are shown separately,

in the form of an alternating sequence rather than a parallel presentation. With regard to the version with captions, a different participant indicated that the German speaking lecturer was distracting and expressed a preference for a version without the lecturer with the entire area being dedicated solely to the slides and captions. Another participant expressed a similar opinion, suggesting that the German speaking lecturer could be made smaller or even omitted altogether.

Regarding the design of the captions, some participants recommended that the captions be customizable in terms of their size, color, and brightness. This flexibility would allow viewers to select a design that is most beneficial for them. One participant additionally noted the importance of ensuring that the captions are not displayed on the slides, which was consistent with the formatting of our videos.

Lecture videos in DGS. Overall, the analysis of the interviews affirms the findings from the quantitative analysis of a general preference for the DGS version of the videos. Additionally, it corroborates the findings regarding the agreement to Statement 1, a compound measure consisting of partially contradictory and competing elements. Moreover, the qualitative analysis highlights that captions (or transcripts) are useful in the context of lecture videos in statistics and mathematics, particularly when technical terms are utilized. However, these results also underline that captioned videos can only complement, but not replace, the DGS version, and that DGS leads to greater subjectively perceived comprehension and interest among deaf participants.

4. CONCLUSION

This preliminary study suggests that deaf participants preferred versions of video lectures in DGS to versions with captions. This finding is apparent in the results of all the presented analyses. Referring to our descriptive analyses, the participants chose a higher level of agreement to the statement “I was able to follow the content of the video” after watching the DGS version with respect to the version with captions. Furthermore, all participants displayed heterogeneous reasoning for the preference for the DGS version over the captions. Many stated that DGS supported a more comprehensive understanding of the content, and that it is crucial to acknowledge the distinction between DGS and written German as two distinct languages. However, some participants indicated that they would utilize captions or transcripts for technical terms. Nevertheless, in all interviews it was evident that the mere provision of captions is insufficient for barrier-free education. One participant in particular asserted that providing captions does not constitute barrier-free information.

Our results thus provide a first empirical evidence of a clear-cut perspective by the Deaf Community that providing captions instead of a DGS translation for videos in higher education is often insufficient, and that the preferred choice of presentation invariably involves some form of DGS-based presentation.

Reflecting upon those findings, it must be stressed that they are based on a very limited sample size and that the findings should accordingly be treated with caution. Furthermore, studies further exploring the exact nature of the aforementioned barriers would be helpful. One potential avenue would be studying the eye movement of deaf students when looking at videos with captions and a sign language interpreter. This would yield insights into how and where an informational overload may cause problems in understanding. An additional approach would be to utilize pre- and post-tests for objective assessment of learning outcomes and to select students exclusively as participants. Last but not least, the potentials and pitfalls of inclusive face-to-face education within blended learning formats can and should be studied to explore how barriers can be reduced there.

For the teaching of statistics as well as any other area, we thus conclude that those lecturers and teachers who aim to adhere to the Convention on the Rights of Persons with Disability should provide teaching materials in the sign language of their respective country. Solely using captions means leaving barriers for deaf students in place. While providing captions is of course a step in the right direction to reduce barriers, the best practice would be to provide several versions of videos, signed, captioned, and signed and captioned, and let students decide what is best for them. With this study, we hope to make a contribution to greater commitment to accessibility in teaching.

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APPENDIX

OPEN INTERVIEW QUESTIONS[5] (translated into English)

First Part: Pre-existing knowledge in mathematics and statistics
- What was mathematics like before?
- Was it fun?
- What role does math play in your everyday/professional life?

Second Part: Questions about the videos

2.1 Impressions of the videos
- What did you like, what did you not like? / What was good, what was bad?
- What is your overall assessment of the comprehensibility of the topics covered in the videos in DGS and the videos with UT?

2.2 Use of the videos
- Would you have liked such videos for your time at school? / Would you have wished for such videos for your time at school?
- In which situations would such videos have been helpful?

2.3 Structure of the videos
- What would you prefer: a video in DGS or with subtitles (or both) or a transcript?
- What did you think of the font size and color of the subtitles?
- What did you think of the background color of the videos? (dark blue or gray)
- What did you think of the two-part structure of the videos with slides and interpreter?
- What did you think of the two-part structure of the videos with slides and lecturer?

[5] Translated into English, the interviews were conducted in DGS